Int Environ Agreements (2020) 20:21–39
https://doi.org/10.1007/s10784-019-09452-9

ORIGINAL PAPER

Understanding the limitations of current RFMO climate change adaptation strategies: the case of the IATTC and the Eastern Pacific Ocean

Brian Pentz[1] · **Nicole Klenk**[1,2]

Accepted: 24 September 2019 / Published online: 5 October 2019

Abstract
While Regional Fisheries Management Organizations (RFMOs) face many challenges in their pursuit of sustainable resource development, climate change is among the most pressing and least addressed. Research has identified a host of expected or ongoing physical, biological, ecological, and social impacts of climate change on the marine environment, creating a strong climate change adaptation imperative for RFMOs. Through a case study of the Inter-American Tropical Tuna Commission (IATTC), we describe two serious limitations of current RFMO climate change adaptation strategies: (1) a weakened efficacy of resource management and conservation policies caused by viewing climate change as a general climate stressor rather than a unique environmental challenge, and (2) a reliance on incremental policy reform, problematic because it may not enable a pace or scale of policy change proportional to the sustainable development challenges created by a rapidly changing ocean. We discuss the benefits and drawbacks of incrementalism and outline potential solutions to the environmental and structural challenges facing the IATTC and other RFMOs, including the concept of adaptation pathways.

Keywords RFMO · Climate change · Adaptive management · Fisheries management · Conservation · IATTC

1 Introduction

The United Nation's Sustainable Development Goals (SDGs) are a suite of 17 goals which identify sustainable development as a central global pursuit and outline targets for its realization (UN 2015). Several SDGs focus on environmental preservation,

✉ Brian Pentz
brian.pentz@mail.utoronto.ca

Nicole Klenk
nicole.klenk@utoronto.ca

1 Department of Physical and Environmental Sciences, University of Toronto, 1265 Military Trail, Scarborough, ON M1C 1A4, Canada

2 Department of Political Science, University of Toronto, 1265 Military Trail, Scarborough, ON M1C 1A4, Canada

a recognition of the importance of the environmental goods and services upon which humans are dependant and the highly concerning status and trends of the climate system (IPCC 2014), the oceans (UNFAO 2018; Pauly and Zeller 2016) and global biodiversity (Butchart et al. 2010; Pereira et al. 2010; IPBES 2019).

Though the SDGs outline environmental goals as discrete areas of concern, there are clear overlaps in the thematic areas they address. Climate change (Goal 13—climate action) and ocean conservation (Goal 14—life below water) are listed as separate goals under the SDG agenda, but overlap in a way that has crucial implications for the individuals, communities, and societies which depend on marine living resources. Documented or expected changes to the marine environment resulting from climate change are expected to include increasing ocean acidification (Hoegh-Guldberg and Bruno 2010; Narita et al. 2012), temperature shifts (IPCC 2014), and variability in large-scale ocean climate events such as the El Niño–Southern Oscillation (ENSO) (Harrison and Chiodi 2015) and the North Atlantic Oscillation (NAO) (Delworth et al. 2016).

The changing physical environment is expected to impact marine life through two pathways: directly, through physiological impacts (Kurihara 2008; Byrne 2011), and indirectly, through ecological mechanisms and habitat impacts (Bromhead et al. 2015). These impact pathways have been identified or theorized for marine ecosystems across tropical (Saunders et al. 2014), temperate (Wernberg et al. 2016), and polar (Frainer et al. 2017) ecosystems, and have been identified as a factor influencing marine biodiversity (McCauley et al. 2015), ocean productivity (Behrenfeld et al. 2006), fisheries production (Brander 2007, 2010; Cheung et al. 2008), catch redistribution (Cheung et al. 2010), recruitment (Britten et al. 2016), species range (Cheung et al. 2013; Gamito et al. 2015; Pinsky et al. 2018), habitat change (Muhling et al. 2011), coral reef health (Hoegh-Guldberg 2011), and altered ecological dynamics (Walther 2010; Doney et al. 2012).

The biological manifestations of climate change will impact commercial fisheries and challenge the institutions responsible for their management (McIlgorm et al. 2010). The impacts of climate change on marine living resources are especially concerning given the decades-long increases in the proportion of overfished stocks (UNFAO 2018) and the status and trends of marine ecosystems (Juan-Jordá et al. 2011; Sumaila et al. 2015). The role fisheries play in global food security (Rice and Garcia 2011; Merino et al. 2012) and economic activity and development around the world, especially in developing states (Allison et al. 2009), further underscores the importance of the implications of climate change for resources and those dependent upon them.

On the high seas, climate change adds further complexity to a resource management context beset with challenges. The management of high seas marine living resources is the responsibility of Regional Fisheries Management Organizations (RFMOs), intergovernmental organizations comprised of states with an interest in the management of such resources. These states are required by Article 118 of the United Nations Convention on the Law of the Sea (UNCLOS) to manage high seas marine living resources cooperatively, and RFMOs are the venues where this cooperation takes place.

RFMOs must be able to adapt to the impacts of climate change if they are to ensure resources under their jurisdiction are developed sustainably. Recent research has started to investigate the question of how RFMOs can adapt to climate change; some work has focused on identifying potential policies and management strategies that could improve climate change adaptation capacity in RFMOs (Brooks et al. 2018), while other research has shown that current RFMO policy frameworks equip RFMOs with climate change adaptation capacity, but that this capacity can be improved (Pentz et al. 2018).

In this paper, we argue that RFMOs possess two types of limitations which restrain their climate change adaptation capacity. The first limitation we identify is rooted in the practise of treating ‘climate change as a subcategory of general climate fluctuations and not as its own distinct environmental challenge’ (Rayfuse 2018). We argue this practise limits the climate change adaptation capacity of RFMOs by limiting the efficacy of risk management strategies and biodiversity conservation policies, and by artificially narrowing the scope of current and prospective policy. The second limitation we outline is the reliance RFMOs have on incremental policy advance as a means to respond to major environmental and resource shifts. We use the Inter-American Tropical Tuna Commission (IATTC) as a case study to provide empirical examples of these limitations.

We structure our analysis in the following way: we first review the role of adaptive management in the RFMO response to climate change, and then outline the climate change challenges of the IATTC and explain why the organization is a valuable proxy for understanding the climate change adaptation challenges facing most other RFMOs. We then describe why designing common fisheries resource management strategies in a way that is not informed by climate change limits adaptation capacity, and then argue that the IATTC's ability to be adequately adaptive to climate change is limited by its political and institutional contexts and its resulting reliance on incremental policy reform. We then discuss the potential for incremental reform to promote sustainable resource development during large-scale resource and environmental change, and outline potential options for the IATTC, and other RFMOs, to improve their ability to adapt to the impacts of climate change.

Climate change has already started to impact the marine environment and marine resources (Pinsky et al. 2018), and if the concerning multidecadal trends of global fisheries (UNFAO 2018) are to be stabilized or improved, effective climate change adaptation is an important area where fisheries management institutions must evolve. Our study contributes towards this imperative.

2 RFMOs, climate change, and adaptive management

Despite its relevance for the fisheries and resources they are tasked with managing, RFMOs, for the most part, have not explicitly addressed climate change in policy frameworks [with CCAMLR being an exception (Rayfuse 2019)]. Axelrod's (2011) study of climate change action across RFMOs found that nine of 17 organizations had undertaken no discernible climate action, and identified only one instance of an RFMO pushing for adaptation activities, and two additional instances of RFMOs requiring both climate change research and adaptation to be undertaken. Thus, across 17 RFMOs between 1992 and 2009, Axelrod (2011) identified only 3 total instances of an RFMO recommending climate change adaptation be undertaken.

In recent work around the question of RFMO engagement with climate change, Rayfuse (2019) delineates the ways in which RFMOs have engaged with climate change into three main pathways: (1) through RFMO-led scientific investigation of the biophysical implications of climate change, (2) through explicit integration of climate change considerations into decision-making processes and decisions, and (3) through climate change-focused changes to resource management policy.

With respect to scientific investigation, the IATTC, the Indian Ocean Tuna Commission (IOTC), the Western and Central Pacific Fisheries Commission (WCPFC), and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) have undertaken scientific research in attempts to understand how climate change will impact the species or ecosystems under their jurisdiction, with CCAMLR having the most extensive research portfolio with respect to climate change (Rayfuse 2019). Regarding the pathway concerning the integration of climate change into decision-making, RFMOs have yet to adopt formal mechanisms for including climate change into decision-making, and thus progress in this pathway is difficult to verify (Rayfuse 2019). Progress in the third, and perhaps most vital pathway, the direct incorporation of climate change into resource policy, has thus far been limited to CCAMLR (Rayfuse 2019), although that RFMO's degree of engagement with climate change has recently been criticized as underdeveloped (Brooks et al. 2018).

To understand why explicit climate change adaptation measures are sparse across RFMOs, it is helpful to place these results in the broader discourse of sustainable fisheries governance. In their attempts to ensure exploitation rates fall within biologically safe limits, RFMOs are predominantly concerned with ensuring that stock biomass does not decrease below precautionary thresholds. But they are also (generally) concerned with biomass *changes*, as changing biomass should precipitate a management response, perhaps in the form of decreased quota, fishing effort, or some other approach that acknowledges and responds to resource flux.

This approach to resource management, where resource contexts and trends are identified and followed by proportional policy response, is an example of adaptive management. Adaptive management is a fundamentally reflexive approach, which relies on iterative policy revision and allows for lessons learned to influence decisions (Holling 1978). It is often cited as having the potential to promote sustainable resource development (Walters and Hilborn 1978; McLain and Lee 1996; Schultz et al. 2015) and has specifically been identified for its climate change adaptation potential (Grafton 2010). While fisheries management institutions, including RFMOs, do not explicitly reference adaptive management as their preferred management approach, the adaptive management cycle [i.e. 'plan, implement, adjust' (Walters 1986)] is evident their activities.

Updating policy approaches as warranted by resource statuses and new understandings of resource bases is an intuitive, simple strategy to manage renewable resources. In this approach, RFMOs do not need to tease apart the factors responsible for resource shift, as the drivers of change are immaterial—it is just the change itself, and its scale, that require identification and response. The precise drivers of this change are of considerably less practical value.

Thus, the practise of adaptive management as a strategy to respond to resource and environmental shift has enabled RFMOs to attempt to respond to climate change implicitly by only requiring them to identify and respond to resource change, without concern for the underlying driver of change. In the following sections of this paper, we argue that this approach carries inherent limitations for climate change adaptation capacity, which we describe further in the following sections.

3 The IATTC as a proxy to understand climate change adaptation challenges

The IATTC, founded in 1949, is among the world's oldest RFMOs. The institution's area of competency covers the eastern Pacific Ocean from 50th parallel north to the 50th parallel south and extends from the west coast of the Americas to 150 degrees longitude. The size of the IATTC's jurisdiction owes to the behaviour of the species it is responsible for managing—tuna are highly migratory and move between coastal ecosystems and the open ocean, and between domestic jurisdictions and international waters. The institution was initially founded by the United States and Costa Rica but has expanded throughout its history; its current membership includes 21 states from Asia, Europe, North America, Oceania, and South America. Five states are currently 'Cooperating Non Members'; Liberia, the only African state active in the Commission, currently has this status.

The IATTC is organized into the Commission (the general body of the IATTC), the Scientific Advisory Committee, the Review Committee (responsible for reviewing the implementation of measures adopted by the Commission), and the Committee on Administration and Finance. The Commission also has various working groups which focus on issues such as fleet capacity, compliance, bycatch, and other institutional priorities and challenges.

The IATTC is an ideal RFMO to serve as a case study to demonstrate the limitations of common climate change adaptation approaches because it shares many core attributes and challenges in common with other RFMOs. These include resource goals, decision-making rules, membership characteristics, jurisdictional challenges, climate change challenges, and climate change adaptation strategies. In this section, we detail these commonalities to show that although RFMOs manage different species and different ecosystems in different regions of the ocean, they share many fundamental settings and challenges in common. This section thus serves to provide context describing the IATTC's climate change challenge, as well as to show that the IATTC is an effective proxy to understand the climate change adaptation challenges facing other RFMOs.

3.1 Common institutional settings

The IATTC's institutional setting shares important similarities with other RFMOs. With respect to resource goals, the IATTC, like most RFMOs, seeks to ensure 'the long-term conservation and sustainable use' of stocks under its jurisdiction (IATTC 2003). The IATTC also includes economic and social outcomes as key considerations in resource decision-making, something other RFMOs also establish in their basic texts.

The IATTC also possesses similar decision-making rules to other RFMOs. The IATTC requires its membership to reach consensus on policy proposals for proposals to be approved, although it is somewhat unique in that it requires all parties to vote, and thus consensus must be achieved without abstentions.

Furthermore, the IATTC's membership is similar to that of the other RFMOs in that its membership is composed of diverse states, including states with different development statuses, resource dependencies, and states which are disproportionally burdened by resource conservation policy (Hanich et al. 2015). Finally, the IATTC's membership, like many RFMOs, has grown substantially since its inception: as noted above, the organization's initial membership consisted only of the USA and Costa Rica, but has expanded to a total of 21 states.

3.2 Common jurisdictional challenges

The jurisdictional challenges the IATTC faces are also common to many RFMOs and are partly a function of the behaviour of the species (albacore (*Thunnus alalunga*), bigeye (*Thunnus obesus*), skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*)), and Pacific bluefin tuna (*Thunnus orientalis*) it is responsible for managing. Tuna are highly migratory and migrate through the domestic waters of various coastal states, such as Peru, Ecuador, Chile, as well as the high seas. Successful management and exploitation of highly migratory species thus heavily depends on the ability the IATTC membership to cooperate in developing and adhering to sustainable development policies. While other tuna RFMOs face precisely this same challenge, other RFMOs also must manage stocks which straddle maritime borders.

3.3 Common exposure to the impacts of climate change

The environment and resources under the jurisdiction of the IATTC, like all RFMOs, will be affected by climate change. We note the universality of climate change impacts for the global ocean in the introduction, but with respect to the IATTC, the physical and physiological impacts of climate change identified for Pacific Ocean tuna include repercussions for spawning and reproduction (Lehodey et al. 2011) and larval growth (Frommel et al. 2016). Indirect effects which have been identified or predicted include habitat impacts (Del Raye and Weng 2015; Robinson et al. 2015; Mislan et al. 2017), and range and distribution shifts (Dueri et al. 2014; Wang et al. 2016). Climate change will also likely impact tuna diets (Olson et al. 2014) and may have implications for stock abundance (Lehodey et al. 2013, 2015; Dueri et al. 2014).

3.4 Similar climate change adaptation approaches

As noted above, and as described by Rayfuse (2018), the extent to which climate change considerations permeate RFMO activities and policies varies. The IATTC's overall consideration of climate change is typical of RFMOs; the organization has conducted scientific inquiry around trying to understand the impacts of climate change and ocean acidification on the populations of species under its jurisdiction—and in this regard is perhaps more advance than most other RFMOs—but climate change considerations are not evident in its decision-making processes or resource and conservation policy (Rayfuse 2019).

The IATTC's approach to guide climate change adaptation policies is thus reliant on traditional adaptive management. Though anachronistic in a world experiencing major environmental change, this approach likely possesses some merit; Pentz et al. (2018) found that several RFMOs possess substantial climate change adaptation capacity, but ranked the IATTC's climate change adaptation capacity 10th out of 12 RFMOs assessed. This suggests the organization is perhaps only moderately equipped to adapt to climate change by its current management framework and incorporation of climate change.

In Sect. 4, we identify three ways in which the IATTC's climate change adaptation approach is limited. In Sect. 5, we look at how the IATTC has attempted to address overcapacity and then discuss the ability of incremental reforms to promote sustainable development during rapid environmental change.

4 Limitations of treating climate change as a general environmental stressor rather than its own distinct environmental challenge

4.1 The precautionary approach

The first limitation created by treating climate change as a general environmental stressor rather than its own distinct environmental challenge (Rayfuse 2018) concerns the ability of the precautionary approach to fully account for the uncertainty and resource risk generated by climate change. Fisheries management institutions often use the ‘precautionary approach’ in an attempt to manage and limit the risk of resource decline created by resource extraction. A common method for implementing the precautionary approach is through the establishment of precautionary limits and reference points on stock biomass or mortality. But there is no uniform prescription of how the precautionary approach can be applied, and as de Bruyn et al. (2013) show, conceptualization, design, and application of the precautionary approach vary between RFMOs.

The stock reference points that often serve as the centrepiece for the application of the precautionary approach are often based on historical understandings of resource bases, ecosystem dynamics, and uncertainty. However, since climate change compounds some baseline uncertainties of fisheries management while creating novel uncertainties in the marine environment, relying on extrapolations of historical understandings to guide precautionary approaches is problematic (Quay 2010; Schindler and Hilborn 2015). Should current understandings of uncertainty fail to capture the actual level of uncertainty with regards to novel, emerging, or no-analog ecosystems, the potential of the approach to mitigate risk may be negatively impacted.

Relatedly, climate change creates a degree of uncertainty in fisheries models and in forecasting ability (Brander 2015; Payne et al. 2015; Cheung et al. 2016). In the context of the IATTC, studies have predicted climate change will result in decreases in tuna production (Lehodey et al. 2010, 2013, 2015; Dueri et al. 2014), while some have predicted production of some species may increase (Dueri et al. 2016), and others project catch increases in specific regions of the Pacific (Bell et al. 2013). Studies have also suggested that climate change will compress tuna habitat (i.e. reduce habitat range to a narrower band of the water column) (Mislan et al. 2017), and further studies have suggested that climate change will alter the magnitude, composition, and distribution of commercial catch in the North Pacific (Woodworth-Jefcoats et al. 2017). Together, these studies suggest a highly concerning and uncertain future for tuna and tuna habitat in the Pacific Ocean.

The IATTC’s record with the precautionary approach is somewhat mixed. Article IV of the organization’s Convention explicitly requires the institution to apply the precautionary approach when information is uncertain, unreliable, or inadequate. The organization, through its Scientific Advisory Committee, has developed Kobe matrices, plots designed to demonstrate biological thresholds and stock statuses and trends, for many of its stocks. The matrices describe the status and trends of spawning stock size relative to maximum sustainable yield and total stock size relative to maximum sustainable yield and are (ideally) used to inform decision-making regarding resource exploitation.

Furthermore, the IATTC has, via Resolution C-16-02, defined how harvest control rules could be used as a tool to further operationalize the precautionary approach. The rules specifically identify stock limits and reference points and provide established standards for management responses when rules are violated. But Resolution C-16-02 only defines limits and reference points, and harvest control rules have yet to be applied by the IATTC in practise.

The IATTC’s application of the precautionary approach is thus not fully operationalized. The creation of Kobe plots and the establishment of harvest control rules are positive developments in the process to exercise precaution. However, neither of these approaches are informed by either our understanding of climate change, or perhaps more appropriately, our *lack* of understanding about the precise nature of the impacts of climate change on the marine environment and marine resources. By pursuing a limited application of the precautionary approach and designing and executing it without accounting for the uniqueness of climate change as an environmental challenge, the IATTC has limited its ability to account for and mitigate the additional resource risk created by climate change.

4.2 The ecosystem approach

The ecosystem approach is a management strategy designed to provide protection for species which are not subject to commercial exploitation, but which nonetheless play important roles in healthy ecosystem functioning. The approach is a crucial component of a climate change adaptation strategy for RFMOs, and according to Rayfuse (2018) 'the approach is generally considered to be the most effective way of enhancing the climate resilience of fisheries'. The approach has also been advocated as a climate change adaptation strategy by others (Heenan et al. 2015). The ecosystem approach and ecosystem considerations are included in RFMO frameworks to different extents: some RFMOs do not establish ecosystem considerations in their Conventions, some define their application of the ecosystem approach as one that attempts to protect non-target species, and others establish protections for ecosystem properties and trophic interactions. Ideal application of the ecosystem approach, according to Juan-Jordá et al. (2018), includes establishing detailed objectives, indicators, and reference points, not only for bycatch, but for ecosystem properties, trophic relationships, and habitats.

The IATTC uses an interpretation of the ecosystem approach (Article VII.1.f) which only identifies the protection of non-commercial or non-target species as the goals for the approach. Specifically, the organization articulates its commitment to protecting ecosystem components as:

> *Article7.1.f* adopt, as necessary, conservation and management measures and recommendations for species belonging to the same ecosystem and that are affected by fishing for, or dependent on or associated with, the fish stocks covered by this Convention, with a view to maintaining or restoring populations of such species above levels at which their reproduction may become seriously threatened.

The IATTC focuses on the populations of non-target species in its ecosystem approach, but does not explicitly note or require trophic interactions, relationships, or habitats to be protected by its Convention. This way in which the IATTC describes its conceptualization of the ecosystem approach is in line with how it pursues ecosystem considerations in practise: Juan-Jordá et al. (2018) found the IATTC has made some progress towards similar protections for species caught as bycatch (for billfishes and marine mammals) but has made little progress towards habitat protections and identification and protection of trophic relationships and ecosystem properties.

The IATTC's application of the ecosystem approach leaves trophic links and habitats and ecosystem properties unprotected and does not provide the institution with a clear path to identify and adapt to the impacts of climate change on these ecosystem components. By establishing and pursuing a narrow definition of the ecosystem approach, the IATTC's ability to protect ecosystem components of marine ecosystems is currently sub-optimal (Juan-Jordá et al. 2018) and, critically, will be weakened as climate change influences the marine environment and marine ecosystems.

It is worth noting that the IATTC's application of the ecosystem approach is fairly typical of RFMOs, if not slightly above average among tuna RFMOs (Juan-Jordá et al. 2018). The IATTC's standard operationalization of the ecosystem approach is another reason why the organization is an effective proxy to understand the limitations of RFMO climate change adaptation approaches.

4.3 Artificial limitation of policy scope

A third limitation created by the view that climate change is simply a general environmental stressor is that it may result in the breadth of fisheries management tools with the capacity to promote climate change adaptation being overlooked. Research has highlighted numerous management options specifically for their capacity to adapt to the impacts climate change on marine species and ecosystems, including input and output controls (Kell et al. 2005; Grafton 2010), gear measures (Cinner et al. 2009), user rights (Ojea et al. 2017), stronger applications of the precautionary approach (Brooks et al. 2018), addressing cumulative impacts (Pinsky and Mantua 2014), more comprehensive applications of the ecosystem approach (Munang et al. 2013), more and better connected marine protected areas (MPAs) (McLeod et al. 2009; Ling and Johnson 2012; Green et al. 2014; Roberts et al. 2017), performance reviews (Pinsky et al. 2018; Pentz et al. 2018), and promotion of socio-ecological resilience (Pinsky and Mantua 2014).

These studies have identified potential policies and governance styles with the potential to improve climate change adaptation. But since the IATTC, like most other RFMOs, views climate change as a general environmental stressor rather than its own distinct challenge (Rayfuse 2018), there is no obvious imperative to consider these policies on the basis of their climate change adaptation potential.

The current approaches to risk management, biodiversity conservation, and policy frameworks are important limitations for the IATTC's ability to effectively adapt to climate change. The seriousness of these limitations is underscored by the importance these policies have assumed in the fisheries management discourse. The precautionary principle and the ecosystem approach have become the primary tools RFMOs rely upon to manage risk and protect biodiversity. Climate change not only impacts risk and biodiversity, but if these approaches do not integrate climate change into their design, climate change impacts our ability to *manage* risk and biodiversity, creating collateral risks to resources, ecosystems, and fishing industries.

5 RFMO climate change adaptation capacity is limited by a reliance on incrementalism

5.1 Adaptive management and consensus-based decision-making

As noted, RFMOs rely on adaptive management to allow them to respond to the impacts of climate change. The approach, however, requires that RFMOs be adequately adaptive, meaning they must capable of responding to change and be able to agree on what policy reforms are appropriate. As we outline in this section, the political and institutional contexts of the IATTC make adaptiveness a complicated quality and make adaptive management difficult to practise.

The IATTC, like many RFMOs, requires that its membership reach consensus on policy proposals. Consensus-based decision-making gives veto power to all members, who can oppose and block reform they perceive as detrimental to their interests. Since many of the policies and strategies with the potential to improve the ability of fisheries management institutions to adapt to climate change carry implications for resource access, reform may face significant political opposition. Consensus-based decision-making rules have specifically been noted to represent a potential issue for climate change adaptation approaches that rely on adaptiveness (Pentz and Klenk 2017).

Consensus-based decision-making could pose a barrier to effective climate change-focused reform at the IATTC. The institution possesses a uniquely high threshold for proposals to be accepted; proposals related to total allowable catch (TAC) levels and allocation require unanimous approval from the membership (with no abstentions) in order to be approved. Given that many potential climate change adaptation policies would influence resource access (see Sect. 4.3), and decisions related to catch levels and resource allocation are among the most politically contentious issues the IATTC faces, this requirement (Article IX.3(b)) has the potential to limit the adaptiveness required to respond to climate change.

The IATTC's membership, owing to its size, growth, and diversity, is particularly susceptible to disagreement and political discord. The IATTC has previously experienced periods where its members were unable to reach consensus over quota. The Commission successfully negotiated and implemented quota allocations between 1966 and 1979, but disagreements over allocation policies starting in 1980 disrupted subsequent efforts to establish and implement quota (Desombre 1999). South American states cited their geographic proximity to resources in arguing for special quota allocations and the ability to make tuna management decisions within their Exclusive Economic Zone (EEZ). The Commission attempted to resolve the dispute by offering special allocations to the South American states, but this move was blocked by Canada and the USA, who wanted to avoid setting a precedent of geographically linked allocations. The dispute had repercussions for the quota system; member states did not implement quota restrictions between 1980 and 1985, and for years following this dispute, no quota restrictions were implemented (Desombre 1999).

However, the IATTC has, despite its complex, diverse, growing membership, and high threshold for decision-making and proposal acceptance, installed noteworthy conservation measures. In 2000, the IATTC accepted the *Resolution on a Regional Vessel Register* (Resolution C-00-01), which formalized a list of vessels authorized to fish for species regulated by IATTC. Subsequent resolutions, including 2002s *Resolution on the capacity of the tuna fleet operating in the Eastern Pacific Ocean (Revised)* (Resolution C-02-03), 2003s *Resolution on large-scale longline vessels* (Resolution C-03-07), and 2008s *Resolution on establishing a program for transshipments by large-scale fishing vessels* (Resolution C-08-02) have established lists of authorized purse-seine vessels, longline vessels, and transshipment vessels (respectively) in an effort to limit capacity. But efforts to limit capacity have not been effective—though Resolution C-02-03 established a target capacity of 158,000 m^3 for the purse-seine fleet; as of April 2017, the fleet's actual capacity was 263,000 m^3 (IATTC 2017).

After years of capacity increase following these capacity resolutions, the IATTC, through Resolutions C-17-01 and C-17-02, have implemented two restrictions from 2018 to 2020: (1) 72-day closures where vessels are not permitted to fish, and (2) restrictions on fish aggregating devices (FADs), pieces of technology which attract tuna and make them easier to catch. The measures outline in these Resolutions are not permanent and will expire in 2020; it remains to be seen whether these measures can reduce capacity to levels associated with sustainable development, or if they can be accepted on a permanent basis.

5.2 Incremental responses to sustainable resource development challenges

Thus consensus-based decision-making is not necessarily an impediment to change and reform which temporarily limits resource access. The route of change the IATTC has pursued, through non-permanent capacity reduction policies that do not reduce the number of fishing vessels, could be described as an 'incremental' approach to policy reform. Incrementalism in public policy can be defined as political change through small, potentially reversible steps (Lindblom 1959). The fact that the IATTC's capacity reduction policies do not require a reduction in the total number of active vessels, and that Resolutions C-17-01 and C-17-02 are not permanent, make these policies examples of small, reversible steps.

This is not to say that the IATTC consciously decides to pursue incremental reform as a strategic decision. Incremental reform is the result of the consensus-based nature of decision-making at the IATTC, its large, diverse membership and sometimes competing interests which combine to make transformative change unlikely. In the next section, we outline the strengths of incremental approaches to policy reform in RFMOs, and then comment on the weaknesses of the approach in the context of rapid global environmental change.

6 Can incrementalism enable sustainable resource development in a rapidly changing ocean?

Thus the IATTC, like all RFMOs with consensus-based decision-making rules and growing, diverse memberships, must likely respond to climate change through incremental policy change. Everson (2017) provides an interesting discussion of incremental approaches to policy change in an RFMO, offering a strategy for Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to make progress towards its goal of establishing a network of marine protected areas (MPAs) in its convention area. CCAMLR first achieved progress towards this network in 2009 by adopting The South Orkney Islands Marine Protected Area (CCAMLR Conservation Measure 91-03). Additional progress towards the network of MPAs was realized slowly as CCAMLR, like the IATTC, requires its members to achieve consensus on policy proposals, and additional MPA proposals were repeatedly opposed by various CCAMLR members (Brooks 2013).

Everson (2017) argued in favour of deliberate incrementalism as a way to break the MPA deadlock. Rather than pursue a single, large MPA unlikely to receive consensus support, Everson (2017) argued in favour of an approach where the various components and characteristics of an MPA could be broken down into different pieces, with each being the subject of an individual agreement. Parties opposing one element or characteristic of the MPA might not block other aspects of the MPA, allowing some protections to proceed.

The benefits of incremental approaches are obvious in terms of improved likelihood of policy approval and capacity building. Progress towards strengthened environmental policies would be more frequent, accepted policies which prove successful in practice can establish path dependencies, and specific elements can be called into question without reopening an entire agreement to re-negotiation (Everson 2017).

But incremental approaches to policy reform carry two major downsides. The first is that incremental advances can be watered-down, temporary half measures lacking the strength to drive tangible progress towards sustainable outcomes. The MPA progress at CCAMLR exemplifies this potential downside of incrementalism. While CCAMLR did not proceed with MPA designation in the piecemeal-style approach recommended by Everson

(2017), the Ross Sea MPA (Conservation Measure 91-05) that eventually resulted from years of negotiation and deadlock is still more incremental than transformative. Where most MPAs are permanent, the Ross Sea MPA contains a sunset clause and expires after 35 years (in 2052). The MPA's design was also altered from its original proposal, with its total size reduced by 30% and ecologically important areas removed (Brooks et al. 2016). Like the IATTC's resolution to limit the capacity of its purse-seine fleet, incremental, non-permanent MPAs may not produce the intended policy goals of resource and ecosystem protection.

A second downside to incremental reform is that the speed of policy reform may not be able to keep pace with the scale of environmental change created by climate change. The breadth and scale of climate change impacts and the pace at which they are occurring (Cheng et al. 2019) likely require fisheries management organizations to pursue comprehensive, meaningful reform of policy frameworks around climate realities. As evidenced by the pace and scale of reform at the IATTC in its pursuit of heightened precaution and lower capacity, and in CCAMLR's protracted MPA negotiation process, RFMOs are not designed to easily achieve transformative policy change, but to pursue incremental advance upon which all parties can agree. It therefore remains uncertain if major environmental and resource change caused by climate change can be addressed effectively through incrementalism.

7 Understanding change in RFMOs

The discussion of how RFMOs change is relevant beyond the matter of climate change adaptation, as RFMOs are likely confined to incremental responses to all the factors challenging their ability to develop resources sustainably. Eliminating overfishing, reducing overcapacity, installing more MPAs, and expanding the precautionary and ecosystem approaches, among other reforms, are likely required if high seas marine living resources are to be sustainably developed over the long-term. But given the increasing size of RFMO memberships and complexity and diversity of interests present, RFMO memberships seem increasingly unlikely to agree upon bold, comprehensive, and transformative departures from the status quo, regardless of the issue at hand.

The fact that the political and institutional contexts at the IATTC and RFMOs more generally select for incremental approaches has implications for marine scientists offering technocratic policy recommendations and analysis which seek to guide RFMOs towards sustainable development. How science can best inform decision-making raises philosophical and political questions not easily answered: What is the practical utility of recommendations advocating for transformative policy reform? How should the problem of climate change adaptation be framed, and by whom? These types of questions are of increasing relevance to RFMOs as they pursue sustainable resource development goals in increasingly large, diverse memberships.

The deep entrenchment of RFMO status quos resulting from institutional barriers and political intricacies complicates the quest for sustainable development. However, it is also an opportunity for marine social science research oriented around the question of institutional change. Multilateral marine resource management organizations have previously undergone fundamental change. The International Whaling Commission, for example, started as a group of whaling states but has evolved to become an organization primarily concerned with preventing whaling. This reorientation (along with the whaling moratoria at the centre of the transformation) has not been universally supported by member states, some of which remain opposed. Hurd (2012) outlines the tension underlying the whaling moratoria, noting the current status quo where some whaling occurs is opposed by both the anti-whaling camp as well as the pro-whaling camp. The anti-whaling camp oppose all commercial whaling, and the pro-whaling camp argues the moratorium is applied to species that are not at risk. Since the IWC requires supermajority support (75%+) to overturn the moratoria, the status quo, which has little approval or support, is essentially solidified, with implications for institutional stability (Hurd 2012). Japan's recent withdrawal from the IWC is perhaps evidence of weakened institutional stability.

Understanding the conditions and scenarios which could puncture RFMO equilibriums and promote transformative departures from the status quo is an important area where research could greatly improve our understanding of RFMOs, how they change, the scale of reform possible under status quo and revolutionary conditions, and institutional stability under these conditions. Such research would be not only beneficial to the discussion of climate change adaptation, but to the entirety of resource management problems RFMOs face.

8 Options to develop climate change adaptation in RFMOs

The concept of adaptation pathways has gained purchase as an approach to guide climate change adaptation. The pathways metaphor is useful to help visualize a 'decision-centred approach to adaptation' by focusing on the 'processes of decision-making and by emphasizing the adaptive natures of the decision process itself in the face of high uncertainty and complexity' (Wise et al. 2014). In reconceptualizing the concept of adaptative pathways towards placing an emphasis on the social change aspects of adaptation, Wise et al. (2014) make a distinction between two different levels at which adaptation can take place simultaneously; (1) the proximate causes of vulnerability that can be addressed incrementally and within contemporary governance structures, and (2) a focus on understanding how existing rules and values influence decision-making to proactively guide systems towards transformative structural change capable of adaptiveness and achieving sustainable development goals.

This dichotomy is instructive for RFMOs, and can be used to analyse RFMO climate adaptation along the climate action engagement pathways (not to be confused with adaptation pathways) outlined by Rayfuse (2019). First, incremental advance within current structures could be pursued through greater engagement with scientific investigation. This would provide RFMOs with improved understanding of resource bases and marine ecosystems under their jurisdiction and would help inform policy. Specifically, research into developing and incorporating climate predictions into adaptive approaches is a potential option for expanding RFMO scientific inquiry. Climate predictions seek to identify the actual state of climate at a particular point in time in the future (as opposed to climate projections, which seek to identify the average climate over long time scales) (Risbey et al. 2014; Dunstan et al. 2018). Climate forecasts could therefore help with resource policy and planning (Dunstan et al. 2018), and could specifically facilitate climate change adaptation practise and planning, particularly for organizations reliant on intertemporal climate adaptation pathways approaches (i.e. Wise et al. 2014).

Additionally, attempts at pursuing incremental advances within current structures which could focus on revising current policy frameworks, including strengthening and extending the application of precautionary approaches and ecosystem approaches, taking additional steps towards a capacity reduction to a level in line with IATTC goals, taking steps towards MPA goals, design, and adoption, including climate change in RFMO performance reviews (Pinsky et al. 2018; Pentz et al. 2018) and other options outlined in Sect. 4.3 and listed in Pentz and Klenk (2017). The cumulative effect of pursuing incremental advance in these areas simultaneously could be significant. Additionally, if policy advance failed in one area, other reform avenues could still represent options for improved climate change adaptation potential.

Systemic change, however, is also required of RFMOs around the idea of explicit incorporation of climate change into decision-making structures (Rayfuse 2019) and process and into resource management and conservation policy (Rayfuse 2019; Brooks et al. 2018). These ways of engaging with climate change can be considered transformative as they would constitute major changes in the decision-making processes and policy design approaches and would not be easily reversible [the latter being one of Lindblom (1959)'s qualities of incrementalism]. Rayfuse (2019) outlines the steps CCAMLR has taken to date, which include a resolution (Resolution 30/XXVIII) recognizing the importance of climate change to the work of the Commission, but a formal mechanism to ensure climate change is factored into decision-making has not been adopted. Design and adoption of this type of mechanism would constitute an important advance and would and enable progress and tracking. This mechanism would not only improve and clarify the extent to which climate change was included in decision, it would provide a rationale for the design and adopt of policies specifically for their adaptation potential. The adaptation pathways approach Wise et al. (2014) outline could help guide institutions towards these changes by conceptualizing adaptation through explicit consideration of the social dimensions of adaptation and how they influence the process.

These conceptual approaches and policy options would represent important advances towards developing the climate change adaptation capacity of RFMOs. However, these options do possess practical and political limitations. First, although long-term climate forecasting could provide knowledge capable of facilitating resource policy and planning, states could leverage the (real or perceived) uncertainty inherent in such predictions to oppose aggressive adaptation efforts they feel impinge on their interests and resource access. Additionally, RFMO scientific bodies do not possess the sort of scientific capacity required to build the models such forecasts would rely on, and developing this capacity could prove difficult given RFMO budgets and possible political opposition to this style of adaptation this research would imply.

Second, the policy options outlined above targeting incremental advance represent several options that could be pursued simultaneously. However, it is important to note that many of these options, especially fleet capacity reduction, have a long and contentious history within the IATTC (and within other RFMOs) and are fraught with political implications and entrenched interests. Incremental advance may therefore be limited to policy options with a less complicated history, such as the inclusion of climate change adaptation into performance reviews. Whether or not incremental advance restricted to less impactful policy could generate significant improvements in climate change capacity is unclear.

Finally, formal changes to the decision-making processes of RFMOs around the idea of mandating that climate change be included would likely be a complicated and protracted reform in many RFMOs. It may be possible for RFMOs to pass resolutions similar to CCAMLR's which acknowledge climate change is an important challenge and requires action, but it would likely be much more difficult to achieve consensus around an explicit mechanism for incorporating climate change into decision-making processes. Opposition to this type of policy change could take many forms, including impacted resource access and reduced sovereignty. Thus while numerous options exist for RFMOs to improve their climate change adaptation potential, many options, including those most likely to drive meaningful reform, may face significant political barriers.

9 Conclusion

The scale and breadth of impacts expected to result from climate change are significant and carry implications for the sustainable development of marine living resources. In this paper, we have argued that the IATTC's current climate change strategies possess two important limitations which likely limit the ability of the IATTC (and other RFMOs practising this style of climate change adaptation) to adapt to the impacts of climate change. The first is a weakened efficacy of current resource management policies, and the second is a structural reliance on incremental policy change, a product of the increasing size and complexity of RFMOs and their use of consensus-based decision-making rules. It is thus unlikely that current RFMO climate change adaptation approaches will be able to ensure sustainable resource development during major environmental change.

Potential reform options to improve RFMO climate change adaptiveness include incremental advances within current governance structures. Incremental advance could drive forward a modicum of progress, but if such reforms are watered-down half measures, they may be unlikely to produce the outcomes they seek. Incremental approaches thus need to be paired with transformative change around structural factors such as decision-making processes and explicit incorporation of climate change into policy design. RFMOs will require both types of progress in order to meet their sustainable development goals.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

Allison, E. H., Perry, A. L., Badjeck, M., Adger, W., Brown, K., Conway, D., et al. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*, *10*(2), 173–196.

Axelrod, M. (2011). Climate change and global fisheries management: linking issues to protect ecosystems or to save political interests? *Global Environmental Politics*, *11*(3), 64–84.

Behrenfeld, M. J., O'Malley, R., Siegel, D. A., McClain, C. R., Sarmiento, J., Feldman, G. C., et al. (2006). Climate-driven trends in contemporary ocean productivity. *Nature*, *444*(7120), 752–755.

Bell, J. D., Ganachaud, A., Gehrke, P. C., Griffiths, S. P., Hobday, A. J., Hoegh-Guldberg, O., et al. (2013). Mixed responses of tropical Pacific fisheries and aquaculture to climate change. *Nature Climate Change*, *3*(6), 591.

Brander, K. M. (2007). Global fish production and climate change. *Proceedings of the National Academy of Sciences*, *104*(50), 19709–19714.

Brander, K. M. (2010). Impacts of climate change on fisheries. *Journal of Marine Systems*, *79*(3), 389–402.

Brander, K. M. (2015). Improving the reliability of fishery predictions under climate change. *Current Climate Change Reports*, *1*(1), 40–48.
Britten, G. L., Dowd, M., & Worm, B. (2016). Changing recruitment capacity in global fish stocks. *Proceedings of the National Academy of Sciences*, *113*(1), 134–139.
Bromhead, D., Scholey, V., Nicol, S., Margulies, D., Wexler, J., Stein, M., et al. (2015). The potential impact of ocean acidification upon eggs and larvae of yellowfin tuna (*Thunnus albacares*). *Deep Sea Research Part II: Topical Studies in Oceanography*, *113*, 268–279.
Brooks, C. M. (2013). Competing values on the Antarctic high seas: CCAMLR and the challenge of marine-protected areas. *The Polar Journal*, *3*(2), 277–300.
Brooks, C. M., Crowder, L. B., Curran, L. M., Dunbar, R. B., Ainley, D. G., Dodds, K. J., Gjerde, K. M. & Sumaila, U. R. (2016). Science-based management indecline in the Southern Ocean. Science, 354(6309), 185–187.
Brooks, C. M., Ainley, D. G., Abrams, P. A., Dayton, P. K., Hofman, R. J., Jacquet, J., et al. (2018). Antarctic fisheries: Factor climate change into their management. *Nature*, *558*(7709), 177–180.
Butchart, S. H., Walpole, M., Collen, B., Van Strien, A., Scharlemann, J. P., Almond, R. E., et al. (2010). Global biodiversity: Indicators of recent declines. *Science*, *328*(5982), 1164–1168.
Byrne, M. (2011). Impact of ocean warming and ocean acidification on marine invertebrate life history stages: Vulnerabilities and potential for persistence in a changing ocean. *Oceanography and Marine Biology: An Annual Review*, *49*, 1–42.
Cheng, L., Abraham, J., Hausfather, Z., & Trenberth, K. E. (2019). How fast are the oceans warming? *Science*, *363*(6423), 128–129.
Cheung, W. W., Close, C., Lam, V., Watson, R., & Pauly, D. (2008). Application of macroecological theory to predict effects of climate change on global fisheries potential. *Marine Ecology Progress Series*, *365*, 187–197.
Cheung, W. W., Jones, M. C., Reygondeau, G., Stock, C. A., Lam, V. W., & Frölicher, T. L. (2016). Structural uncertainty in projecting global fisheries catches under climate change. *Ecological Modelling*, *325*, 57–66.
Cheung, W. W., Lam, V. W., Sarmiento, J. L., Kearney, K., Watson, R. E. G., Zeller, D., et al. (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, *16*(1), 24–35.
Cheung, W. W., Watson, R., & Pauly, D. (2013). Signature of ocean warming in global fisheries catch. *Nature*, *497*(7449), 365–368.
Cinner, J. E., McClanahan, T., Graham, N. A., Pratchett, M. S., Wilson, S. K., & Raina, J. B. (2009). Gear-based fisheries management as a potential adaptive response to climate change and coral mortality. *Journal of Applied Ecology*, *46*(3), 724–732.
de Bruyn, P., Murua, H., & Aranda, M. (2013). The Precautionary approach to fisheries management: How this is taken into account by Tuna regional fisheries management organisations (RFMOs). *Marine Policy*, *38*, 397–406.
Delworth, T. L., Zeng, F., Vecchi, G. A., Yang, X., Zhang, L., & Zhang, R. (2016). The North Atlantic Oscillation as a driver of rapid climate change in the Northern Hemisphere. *Nature Geoscience*, *9*(7), 509.
Del Raye, G., & Weng, K. C. (2015). An aerobic scope-based habitat suitability index for predicting the effects of multi-dimensional climate change stressors on marine teleosts. *Deep Sea Research Part II: Topical Studies in Oceanography*, *113*, 280–290.
Desombre, E. (1999). Tuna fishing and common pool resources. In J. S. Barkin & G. E. Shambaugh (Eds.), *Anarchy and the environment: The international relations of common pool resources* (pp. 51–69). New York: State University of New York Press.
Doney, S. C., Ruckelshaus, M., Duffy, J. E., Barry, J. P., Chan, F., English, C. A., et al. (2012). Climate change impacts on marine ecosystems. *Annual Review of Marine Science*, *4*, 11–37.
Dueri, S., Bopp, L., & Maury, O. (2014). Projecting the impacts of climate change on skipjack tuna abundance and spatial distribution. *Global Change Biology*, *20*(3), 742–753.
Dueri, S., Guillotreau, P., Jiménez-Toribio, R., Oliveros-Ramos, R., Bopp, L., & Maury, O. (2016). Food security or economic profitability? Projecting the effects of climate and socioeconomic changes on global skipjack tuna fisheries under three management strategies. *Global Environmental Change*, *41*, 1–12.
Dunstan, P. K., Moore, B. R., Bell, J. D., Holbrook, N. J., Oliver, E. C., Risbey, J., et al. (2018). How can climate predictions improve sustainability of coastal fisheries in Pacific Small-Island Developing States? *Marine Policy*, *88*, 295–302.
Everson, I. (2017). Designation and management of large-scale MPAs drawing on the experiences of CCAMLR. *Fish and Fisheries*, *18*(1), 145–159.

Frainer, A., Primicerio, R., Kortsch, S., Aune, M., Dolgov, A. V., Fossheim, M., et al. (2017). Climate-driven changes in functional biogeography of Arctic marine fish communities. *Proceedings of the National Academy of Sciences*, *114*(46), 12202–12207.

Frommel, A. Y., Margulies, D., Wexler, J. B., Stein, M. S., Scholey, V. P., Williamson, J. E., et al. (2016). Ocean acidification has lethal and sub-lethal effects on larval development of yellowfin tuna, *Thunnus albacares*. *Journal of Experimental Marine Biology and Ecology*, *482*, 18–24.

Gamito, R., Costa, M. J., & Cabral, H. N. (2015). Fisheries in a warming ocean: trends in fish catches in the large marine ecosystems of the world. *Regional Environmental Change*, *15*(1), 57–65.

Grafton, R. Q. (2010). Adaptation to climate change in marine capture fisheries. *Marine Policy*, *34*(3), 606–615.

Green, A. L., Fernandes, L., Almany, G., Abesamis, R., McLeod, E., Aliño, P. M., et al. (2014). Designing marine reserves for fisheries management, biodiversity conservation, and climate change adaptation. *Coastal Management*, *42*(2), 143–159.

Hanich, Q., Campbell, B., Bailey, M., & Molenaar, E. (2015). Research into fisheries equity and fairness—Addressing conservation burden concerns in transboundary fisheries. *Marine Policy*, *51*, 302–304.

Harrison, D. E., & Chiodi, A. M. (2015). Multi-decadal variability and trends in the El Nino-Southern oscillation and tropical pacific fisheries implications. *Deep-Sea Research Part II-Topical Studies in Oceanography*, *113*, 9–21.

Heenan, A., Pomeroy, R., Bell, J., Munday, P. L., Cheung, W., Logan, C., et al. (2015). A climate-informed, ecosystem approach to fisheries management. *Marine Policy*, *57*, 182–192.

Hoegh-Guldberg, O. (2011). Coral reef ecosystems and anthropogenic climate change. *Regional Environmental Change*, *11*(1), 215–227.

Hoegh-Guldberg, O., & Bruno, J. F. (2010). The impact of climate change on the World's marine ecosystems. *Science*, *328*(5985), 1523–1528.

Holling, C. S. (1978). *Adaptive environmental assessment and management*. New York: Wiley.

Hurd, I. (2012). Almost saving whales: The ambiguity of success at the International Whaling Commission. *Ethics & International Affairs*, *26*(1), 103–112.

IATTC. (2003). Convention for the Strengthening of the Inter-American Tropical Tuna Commission Established by the 1949 Convention between the United States of America and the Republic of Costa Rica (Antigua Convention).

IATTC. (2017). IATTC Scientific Advisory Committee—Eight Meeting Report of the Meeting. https://www.iattc.org/Meetings/Meetings2017/SAC-08/PDFs/Docs/_English/SAC-08-RPT_8th-Meeting-of-the-Scientific-Advisory-Committee.pdf. Accessed 10 July 2019.

IPBES. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services. Available at: https://cdn2.hubspot.net/hubfs/4783129/Summary%20for%20Policymakers%20IPBES%20Global%20Assessment.pdf?__hstc=&__hssc=&hsCtaTracking=91fd55c1-7918-40d1-a145-73e8dab568a9%7C67bf054a-fcc7-448e-9235-42416b2b6e88. Accessed 10 July 2019.

IPCC. (2014). Climate Change 2014: Synthesis Report Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, RK Pachauri and LA Meyer (eds)] IPCC, Geneva, Switzerland, 151 pp.

Juan-Jordá, M., Mosqueira, I., Cooper, A. B., Freire, J., & Dulvy, N. K. (2011). Global population trajectories of tunas and their relatives. *PNAS*, *108*, 20650–20655.

Juan-Jordá, M., Murua, H., Arrizabalaga, H., Dulvy, N. K., & Restrepo, V. (2018). Report card on ecosystem-based fisheries management in tuna regional fisheries management organizations. *Fish and Fisheries*, *19*(2), 321–339.

Kell, L. T., Pilling, G. M., & O'Brien, C. M. (2005). Implications of climate change for the management of North Sea cod (*Gadus morhua*). *ICES Journal of Marine Science*, *62*(7), 1483–1491.

Kurihara, H. (2008). Effects of CO_2-driven ocean acidification on the early developmental stages of invertebrates. *Marine Ecology Progress Series*, *373*, 275–284.

Lehodey P., Hampton J., Brill R.W., Nicol S., Senina I., Calmettes B., et al. (2011). Vulnerability of oceanic fisheries in the tropical Pacific to climate change. In: J. Bell, J. E. Johnson and A. J. Hobday (Eds.), *Vulnerability of tropical pacific fisheries and aquaculture to climate change*. Secretariat of the Pacific Community, New Caledonia.

Lehodey, P., Senina, I., Calmettes, B., Hampton, J., & Nicol, S. (2013). Modelling the impact of climate change on Pacific skipjack tuna population and fisheries. *Climatic Change*, *119*(1), 95–109.

Lehodey, P., Senina, I., Nicol, S., & Hampton, J. (2015). Modelling the impact of climate change on south pacific albacore tuna. *Deep-Sea Research Part II-Topical Studies in Oceanography*, *113*, 246–259.

Lehodey, P., Senina, I., Sibert, J., Bopp, L., Calmettes, B., Hampton, J., et al. (2010). Preliminary forecasts of Pacific bigeye tuna population trends under the A2 IPCC scenario. *Progress in Oceanography*, *86*(1–2), 302–315.

Lindblom, C. E. (1959). The science of muddling through. *Public Administration Review*, *19*(2), 79–88.

Ling, S. D., & Johnson, C. R. (2012). Marine reserves reduce risk of climate-driven phase shift by reinstating size-and habitat-specific trophic interactions. *Ecological Applications*, *22*(4), 1232–1245.

McCauley, D. J., Pinsky, M. L., Palumbi, S. R., Estes, J. A., Joyce, F. H., & Warner, R. R. (2015). Marine defaunation: Animal loss in the global ocean. *Science*, *347*(6219), 1255641.

McLain, R. J., & Lee, R. G. (1996). Adaptive management: Promises and pitfalls. *Environmental management*, *20*(4), 437–448.

McLeod, E., Salm, R., Green, A., & Almany, J. (2009). Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and the Environment*, *7*(7), 362–370.

McIlgorm, A., Hanna, S., Knapp, G., Le Floc'H, P., Millerd, F., & Pan, M. (2010). How will climate change alter fishery governance? Insights from seven international case studies. *Marine Policy*, *34*(1), 170–177.

Merino, G., Barange, M., Blanchard, J. L., Harle, J., Holmes, R., Allen, I., et al. (2012). Can marine fisheries and aquaculture meet fish demand from a growing human population in a changing climate? *Global Environmental Change*, *22*(4), 795–806.

Mislan, K. A. S., Deutsch, C. A., Brill, R. W., Dunne, J. P., & Sarmiento, J. L. (2017). Projections of climate driven changes in tuna vertical habitat based on species-specific differences in blood oxygen affinity. *Global Change Biology*, *23*(10), 4019–4028.

Muhling, B. A., Lee, S.-K., Lamkin, J. T., & Liu, Y. (2011). Predicting the effects of climate change on bluefin tuna (*Thunnus thynnus*) spawning habitat in the Gulf of Mexico. *ICES Journal of Marine Science*, *68*, 1051–1062.

Munang, R., Thiaw, I., Alverson, K., Mumba, M., Liu, J., & Rivington, M. (2013). Climate change and ecosystem-based adaptation: A new pragmatic approach to buffering climate change impacts. *Current Opinion in Environmental Sustainability*, *5*(1), 67–71.

Narita, D., Rehdanz, K., & Tol, R. S. (2012). Economic costs of ocean acidification: A look into the impacts on global shellfish production. *Climatic Change*, *113*(3–4), 1049–1063.

Olson, R. J., Duffy, L. M., Kuhnert, P. M., Galvan-Magana, F., Bocanegra-Castillo, N., & Alatorre-Ramirez, V. (2014). Decadal diet shift in yellowfin tuna *Thunnus albacares* suggests broad-scale food web changes in the eastern tropical Pacific Ocean. *Marine Ecology Progress Series*, *497*, 157–178.

Ojea, E., Pearlman, I., Gaines, S. D., & Lester, S. E. (2017). Fisheries regulatory regimes and resilience to climate change. *Ambio*, *46*(4), 399–412.

Pauly, D., & Zeller, D. (2016). Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications*, *7*, pncomms10244.

Payne, M. R., Barange, M., Cheung, W. W., MacKenzie, B. R., Batchelder, H. P., Cormon, X., et al. (2015). Uncertainties in projecting climate-change impacts in marine ecosystems. *ICES Journal of Marine Science*, *73*(5), 1272–1282.

Pentz, B., & Klenk, N. (2017). The 'responsiveness gap' in RFMOs: The critical role of decision-making policies in the fisheries management response to climate change. *Ocean & Coastal Management*, *145*, 44–51.

Pentz, B., Klenk, N., Ogle, S., & Fisher, J. A. D. (2018). Can regional fisheries management organizations (RFMOs) manage resources effectively during climate change? *Marine Policy*, *92*, 13–20.

Pereira, H. M., Leadley, P. W., Proença, V., Alkemade, R., Scharlemann, J. P., Fernandez-Manjarrés, J. F., et al. (2010). Scenarios for global biodiversity in the 21st century. *Science*, *330*(6010), 1496–1501.

Pinsky, M. L., & Mantua, N. J. (2014). Emerging adaptation approaches for climate-ready fisheries management. *Oceanography*, *27*(4), 146–159.

Pinsky, M. L., Reygondeau, G., Caddell, R., Palacios-Abrantes, J., Spijkers, J., & Cheung, W. W. (2018). Preparing ocean governance for species on the move. *Science*, *360*(6394), 1189–1191.

Quay, R. (2010). Anticipatory governance: A tool for climate change adaptation. *Journal of the American Planning Association*, *76*(4), 496–511.

Rayfuse, R. (2018). Climate change and antarctic fisheries: Ecosystem management in CCAMLR. *Ecology LQ*, *45*, 53.

Rayfuse, R. (2019). Addressing climate change impacts in regional fisheries management organizations. In R. Caddell & E. J. Molenaar (Eds.), *Strengthening international fisheries law in an era of changing oceans* (pp. 247–268). Oxford: Hart Publishing.

Rice, J. C., & Garcia, S. M. (2011). Fisheries, food security, climate change, and biodiversity: Characteristics of the sector and perspectives on emerging issues. *ICES Journal of Marine Science*, *68*, 1343–1353.

Risbey, J. S., Lewandowsky, S., Langlais, C., Monselesan, D. P., O'Kane, T. J., & Oreskes, N. (2014). Well-estimated global surface warming in climate projections selected for ENSO phase. *Nature Climate Change*, *4*(9), 835.

Roberts, C. M., O'Leary, B. C., McCauley, D. J., Cury, P. M., Duarte, C. M., Lubchenco, J., et al. (2017). Marine reserves can mitigate and promote adaptation to climate change. *Proceedings of the National Academy of Sciences*, *114*(24), 6167–6175.

Robinson, L. M., Hobday, A. J., Possingham, H. P., & Richardson, A. J. (2015). Trailing edges projected to move faster than leading edges for large pelagic fish habitats under climate change. *Deep-Sea Research Part II: Topical Studies in Oceanography*, *113*, 225–234.

Saunders, M. I., Leon, J. X., Callaghan, D. P., Roelfsema, C. M., Hamylton, S., Brown, C. J., et al. (2014). Interdependency of tropical marine ecosystems in response to climate change. *Nature Climate Change*, *4*(8), 724–729.

Schindler, D. E., & Hilborn, R. (2015). Prediction, precaution, and policy under global change. *Science*, *347*(6225), 953–954.

Schultz, L., Folke, C., Österblom, H., & Olsson, P. (2015). Adaptive governance, ecosystem management, and natural capital. *Proceedings of the National Academy of Sciences*, *112*(24), 7369–7374.

Sumaila, U. R., Lam, V. W. Y., Miller, D. D., Teh, L., Watson, R., Zeller, D., et al. (2015). Winners and losers in a world where the high seas is closed to fishing. *Scientific Reports*, *5*, 8481. https://doi.org/10.1038/srep08481.

UN. (2015). *Transforming our world: The 2030 agenda for sustainable development*. A/RES/70/1.

UNFAO. (2018). The State of World Fisheries and Aquaculture 2018—Meeting the sustainable development goals. Rome Licence: CC BY-NC-SA 30 IGO.

Walters, C. J. (1986). *Adaptive management of renewable resources*. New York, NY: Macmillan Publishers Ltd.

Walters, C. J., & Hilborn, R. (1978). Ecological optimization and adaptive management. *Annual Review of Ecology and Systematics*, *9*(1), 157–188.

Walther, G. R. (2010). Community and ecosystem responses to recent climate change. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1549), 2019–2024.

Wang, J., Chen, X., & Chen, Y. (2016). Spatio-temporal distribution of skipjack in relation to oceanographic conditions in the west-central Pacific Ocean. *International Journal of Remote Sensing*, *37*(24), 6149–6164.

Wernberg, T., Bennett, S., Babcock, R. C., de Bettignies, T., Cure, K., Depczynski, M., et al. (2016). Climate-driven regime shift of a temperate marine ecosystem. *Science*, *353*(6295), 169–172.

Wise, R. M., Fazey, I., Smith, M. S., Park, S. E., Eakin, H. C., Van Garderen, E. A., et al. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change*, *28*, 325–336.

Woodworth-Jefcoats, P. A., Polovina, J. J., & Drazen, J. C. (2017). Climate change is projected to reduce carrying capacity and redistribute species richness in North Pacific pelagic marine ecosystems. *Global Change Biology, 23*(3), 1000–1008.